

# **Signal Processing Architectures for Ultra-Wideband Wide-Angle Synthetic Aperture Radar Applications**

**Atindra Mitra  
AFRL/SNRR**

**Joe Germann  
SKY Computers**

**John Nehrbass  
ASC/HPC**

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# Abstract



Approaches for parallel implementation of real-time image formation processing (IFP) for ultra-wideband wide-angle synthetic aperture radar (SAR) are discussed. Integration over wide-angles and ultra-wideband waveforms are typically required for applications with low operating frequencies as well as other important applications [1] [2] [3]. The wide integration angles and ultra-wideband (UWB) waveforms that are implemented for these type of state-of-the-art systems are intended to compensate for a loss in resolution in relation to systems that operate under standard systems parameters. State-of-the-art SAR image formation algorithms that address this ultra-wideband wide-angle problem includes time-domain backprojection-type algorithms and Fourier-based processing algorithms. An analysis of these algorithms in terms of computational gains as a function of HPC implementation parameters is presented. A sample set of simulation results are included that illustrate the trade-offs between image quality and computational efficiency. In addition, a discussion of approaches to implementing IFP post-processing algorithms that specifically address the real-time nature of this problem are presented.



# Basic Approaches To SAR IFP For Purposes Of This Investigation



- **Fourier-Based Approach With Mo-Comp to Scene Center [2]**
  - Traditionally Considered Computationally Efficient Frequency-Domain Technique for Purposes Real-Time Implementation [1] [2]
  - Image Quality Tends to Degrade with Distance from Scene Center
- **Time-Domain Backprojection [1]**
  - Even “Fast” Versions Traditionally Considered Too Computationally Intensive for Real-Time Airborne SAR IFP [3]
  - Generates High-Quality Imagery
  - Simulation Results Presented with Various Levels of Accuracy for Interpolator:  
nratio = 1 , 2 , 8 , 20 , 50 , 100 , 200  
where nratio is a “upsampling factor” for each time-domain radar pulse
- **Fourier-Based Approach with Post-Processing [1] [2]**
  - Also with Mo-Comp to Scene Center as with Approach 1 Above
  - Advanced Post-Processing Techniques Show Potential for Auto-Correction of Possible Sensor Calibration Errors Due to a Number of Physical Effects
  - This Block-by-Block Post-Processing is Performed at the Expense of Computational Efficiency



# Six Notional Simulation Cases Defined For Comparative Investigation [1]



- case 1       $X_c=1000$        $X_0=100$        $Y_0=120$
- case 2       $X_c=5000$        $X_0=100$        $Y_0=120$
- case 3       $X_c=6000$        $X_0=240$        $Y_0=222$
- case 4       $X_c=6000$        $X_0=480$        $Y_0=480$
- case 5       $X_c=6000$        $X_0=600$        $Y_0=600$
- case 6       $X_c=6000$        $X_0=960$        $Y_0=886$

Where, for a given set of SAR system parameters,  $X_c$  is the Distance From the Platform to Scene Center in Meters,  $X_0$  is the Range Dimension of the Scene Size in Meters, and  $Y_0$  is the Cross-Range Dimension of the Scene Size in Meters

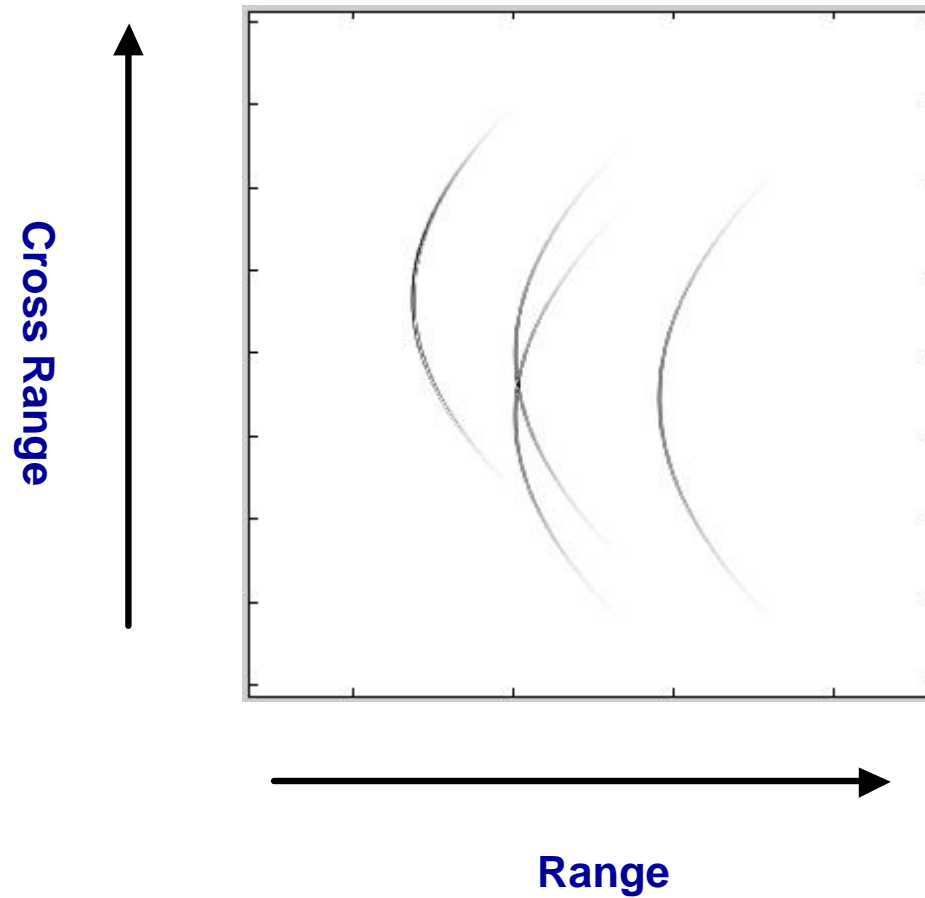
Case 1 (with total of all algorithms and all sets of algorithm parameters) executes in ~ 2.5 minutes on SOA single-processor PC with 512 Mbytes of RAM

Case 6 (with total all algorithms and all sets of algorithm parameters) executes in ~ 15 hours on SOA single-processor PC with 512 Mbytes of RAM



# Sample Simulation Output

## Simulated Wide-Angle SAR Signal



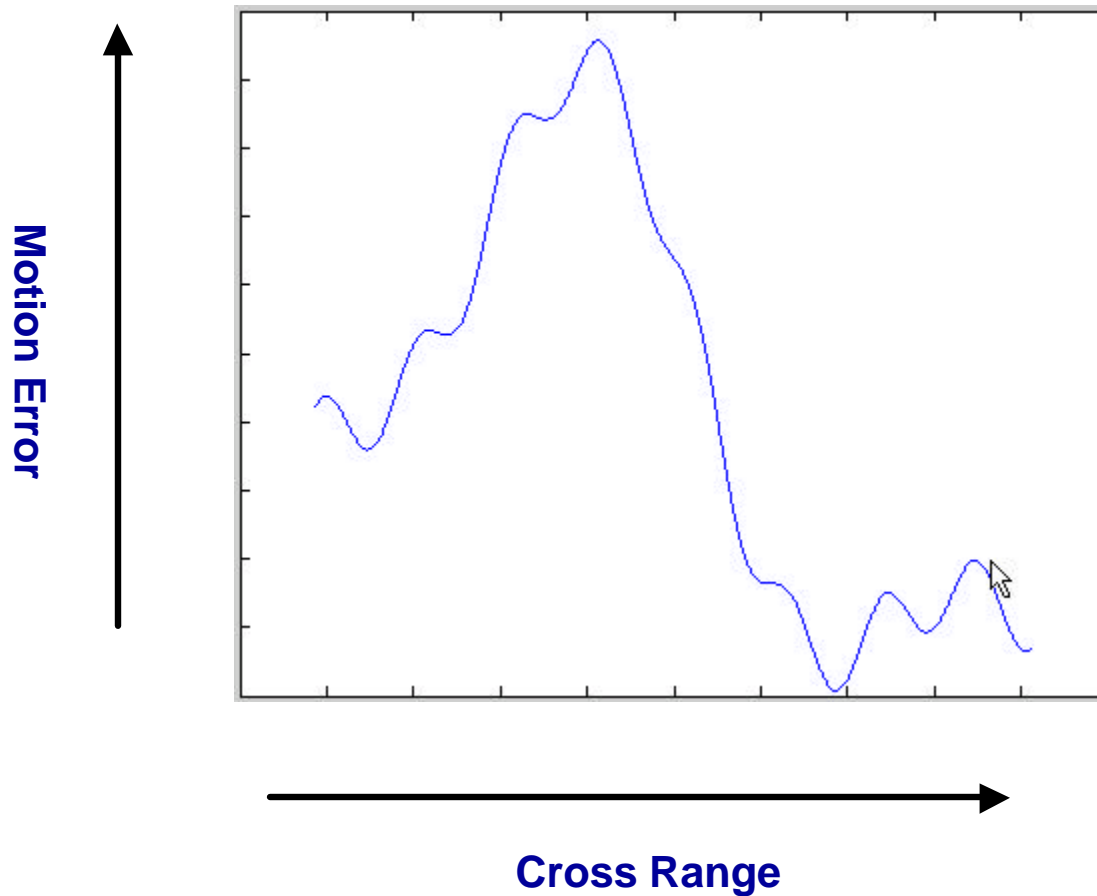


# Sample Simulation Output

Model for Small Residual Error Signal

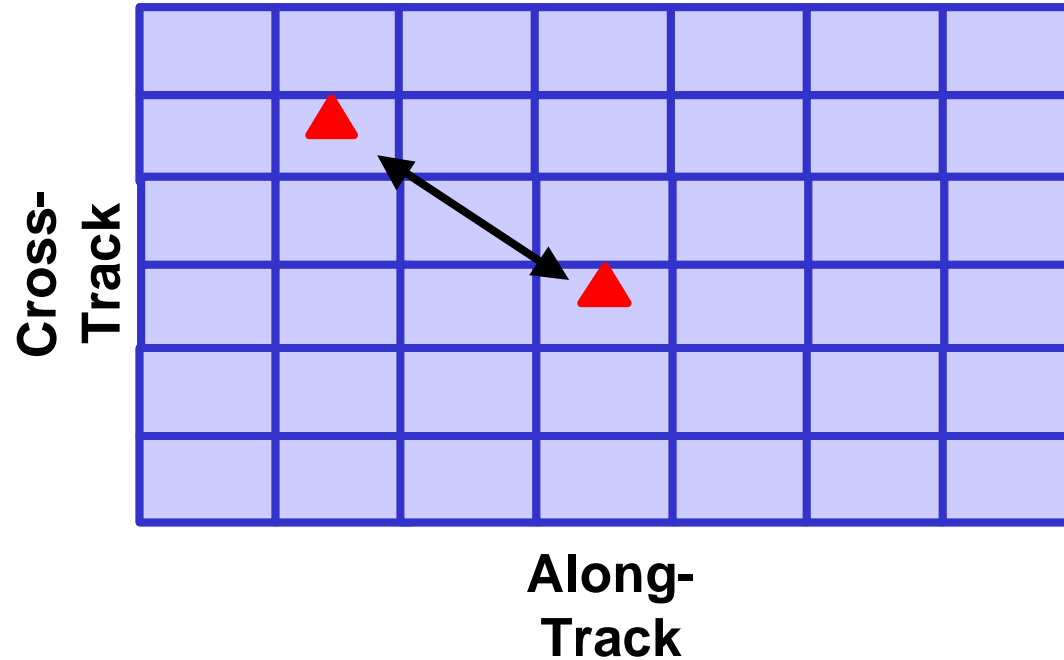


**Small Residual Error Signal  
Is Injected Into Signal On Previous Chart**





# HPC Approach For Fourier-Based IFP and Auto-Cal Post-Processing



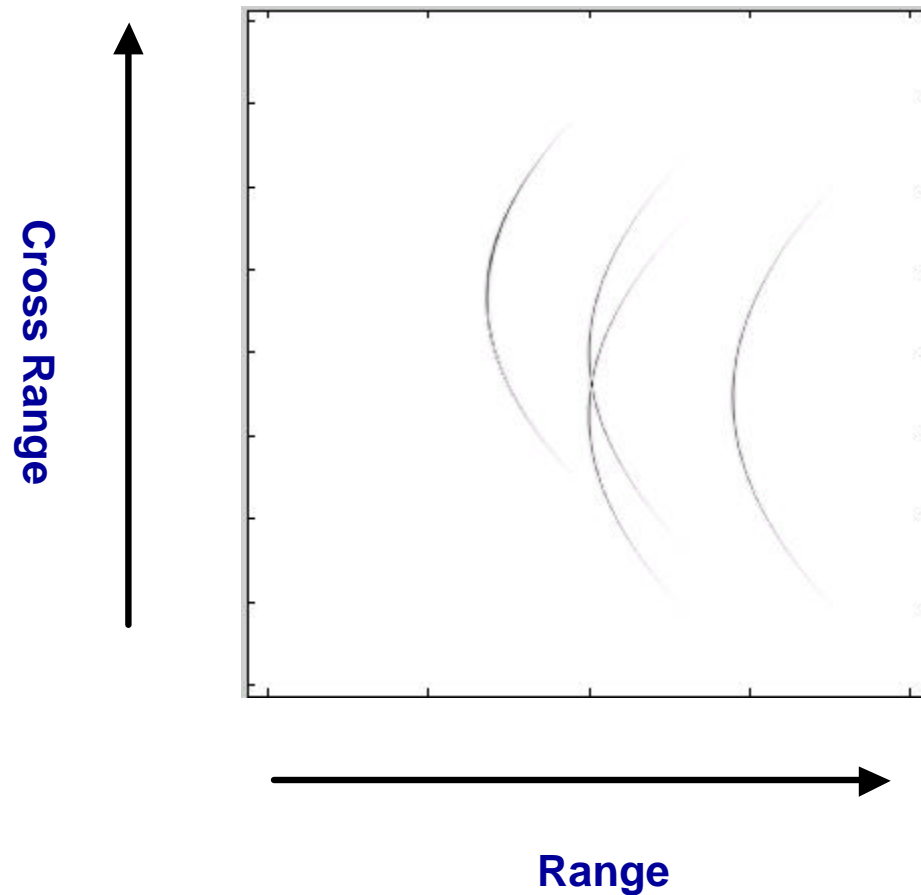
HPC Resource Management and Communications Paradigm Is Designed Such That Each Processor Is Assigned A Group of Localized Windows For Intensive Auto-Cal Post-Processing. The Computational Load Per Processor Is Determined By The Total Of Localized Windows That Are Selected And The Number Of Processors. This Block-by-Block Auto-Cal Post-Processing Is Intended To “Re-Calibrate” Localized Regions Of The Image For Mo-Comp Errors During The Fourier-Based IFP Which Performs Mo-Comp To Scene Center and To “Re-Calibrate” Localized Regions Due to Residual “Time Dependent” Sensor Fluctuations





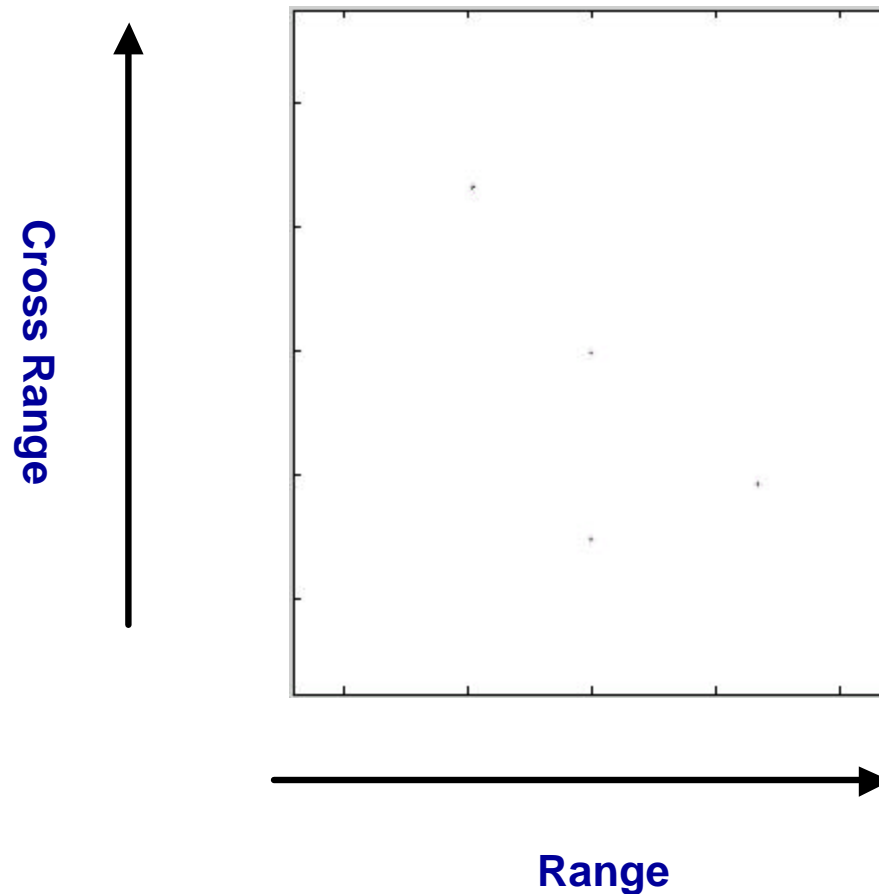
# Sample Simulation Output

## After Matched Filtering in Range Dimension





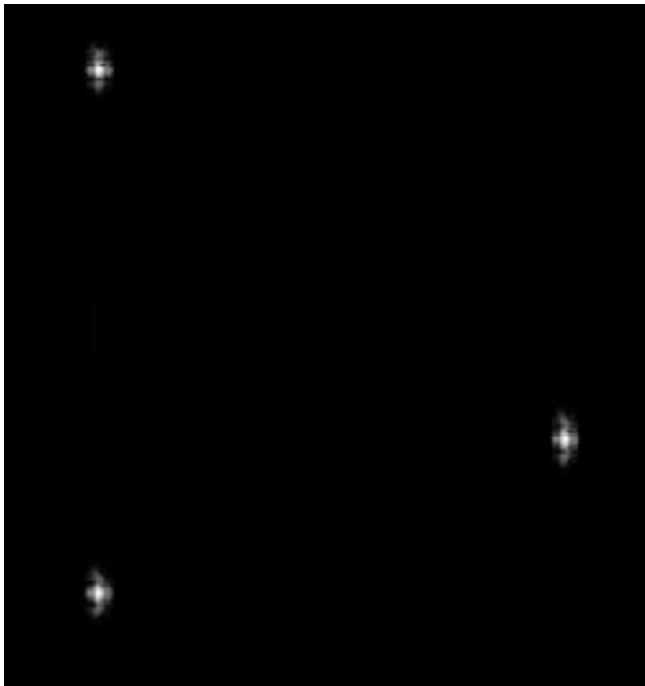
# Sample Simulation Output



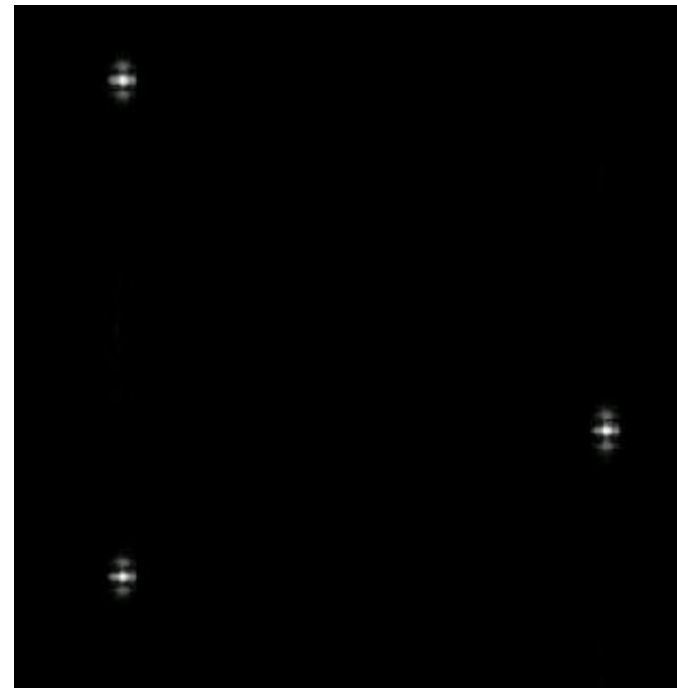
After Matched Filtering  
in Cross Range and  
Interpolation To  
Compensate for Range  
Migration and Range  
Curvature Due To Wide-  
Angle IFP Process for  
UWB Radar Application



# Sample Simulation Output



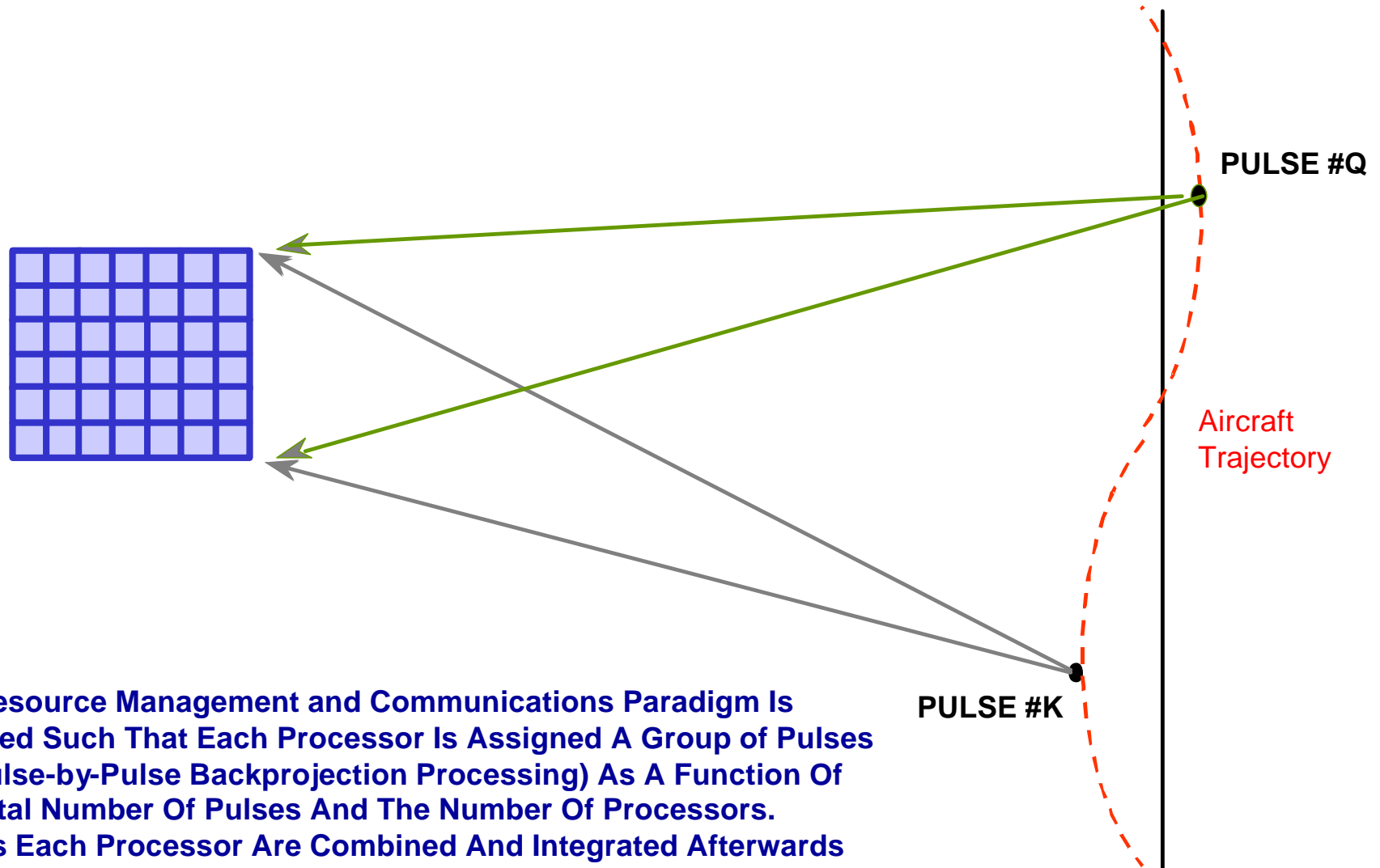
W/O Auto-Cal Post-Processing



With Auto-Cal Post-Processing



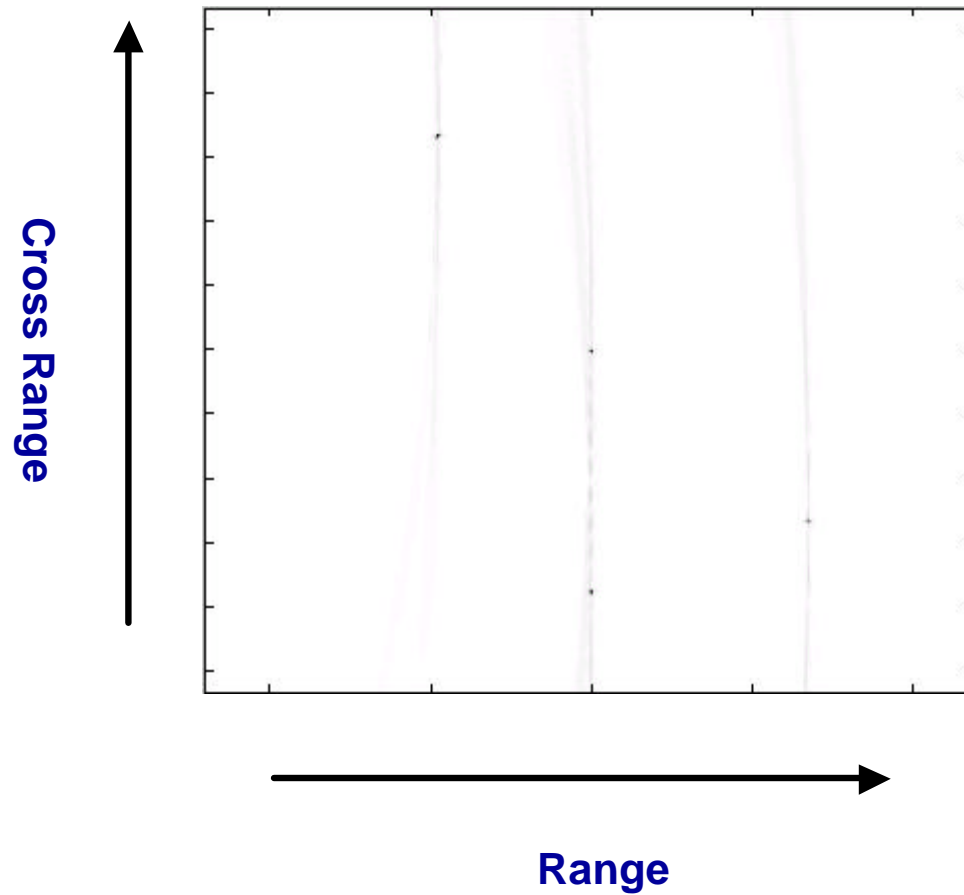
# HPC Approach For Backprojection Implementation





# Sample Simulation Output

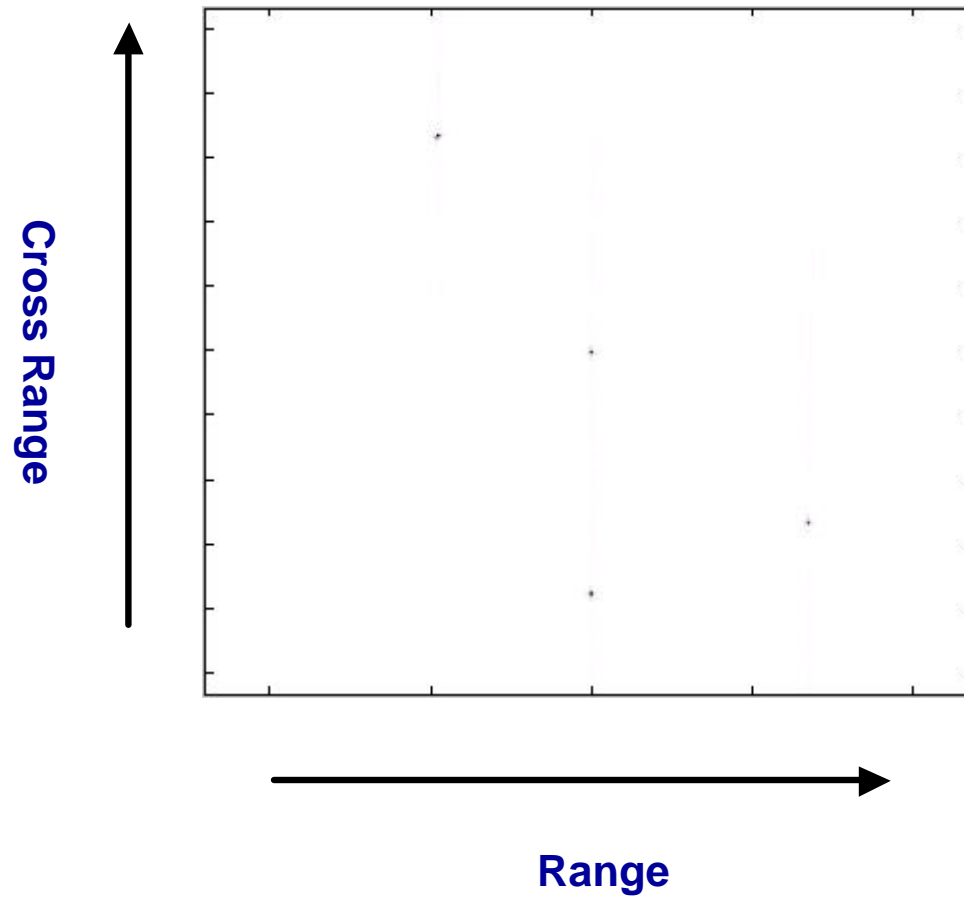
$n\_ratio = 1$





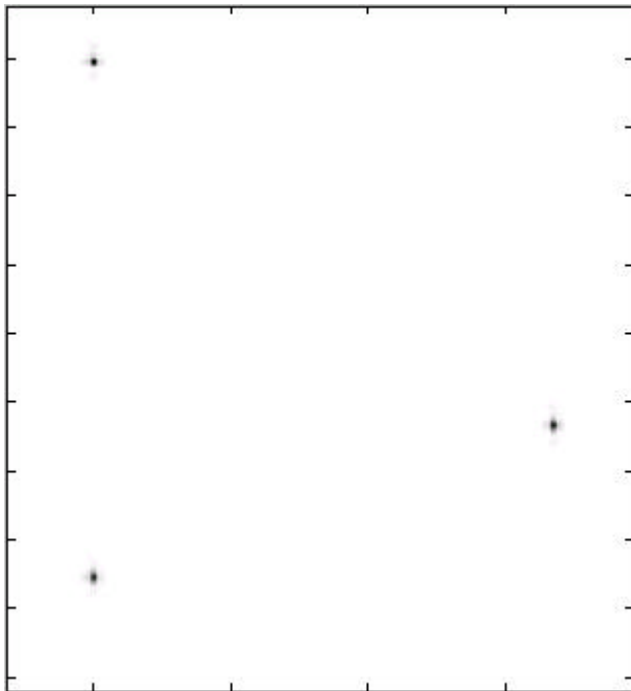
# Sample Simulation Output

$n\_ratio = 2$

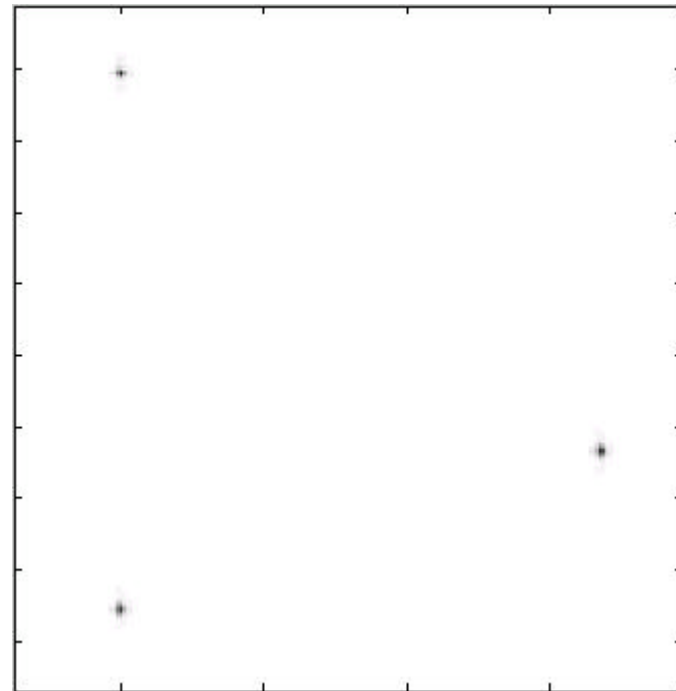




# Sample Simulation Output



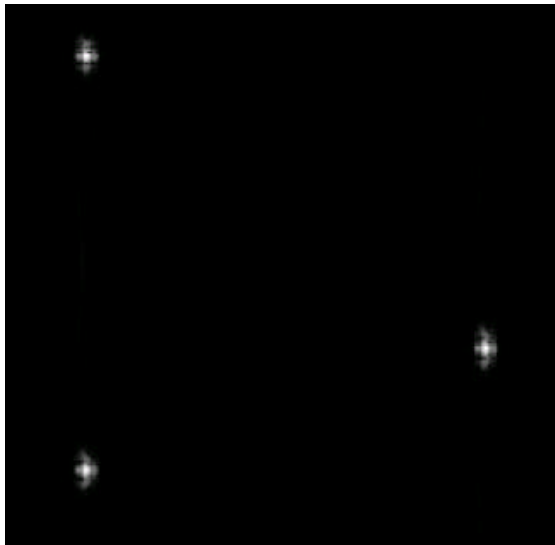
**n\_ratio = 20**



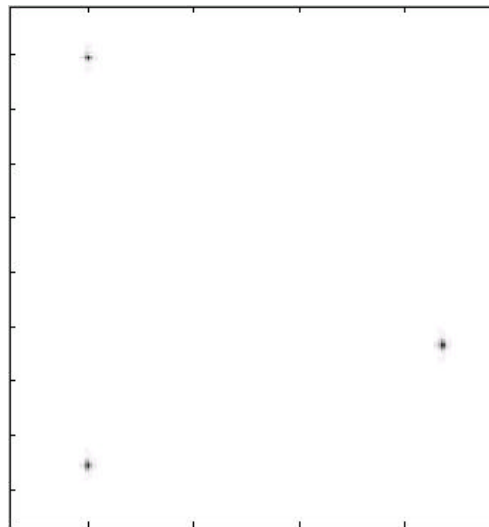
**n\_ratio = 200**



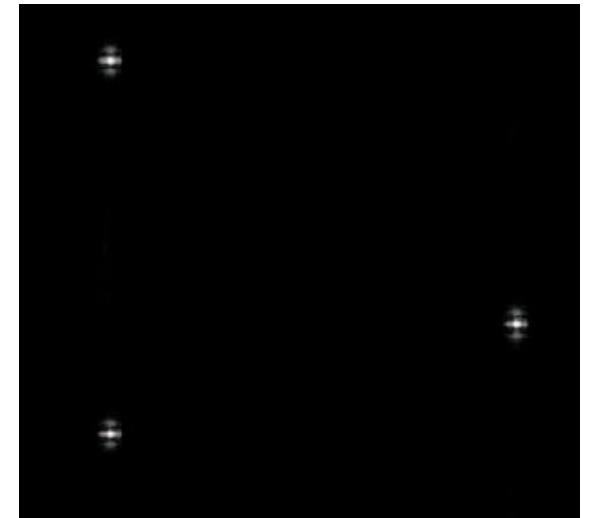
# Sample Simulation Output



W/O Auto-Cal



$n\_ratio = 200$



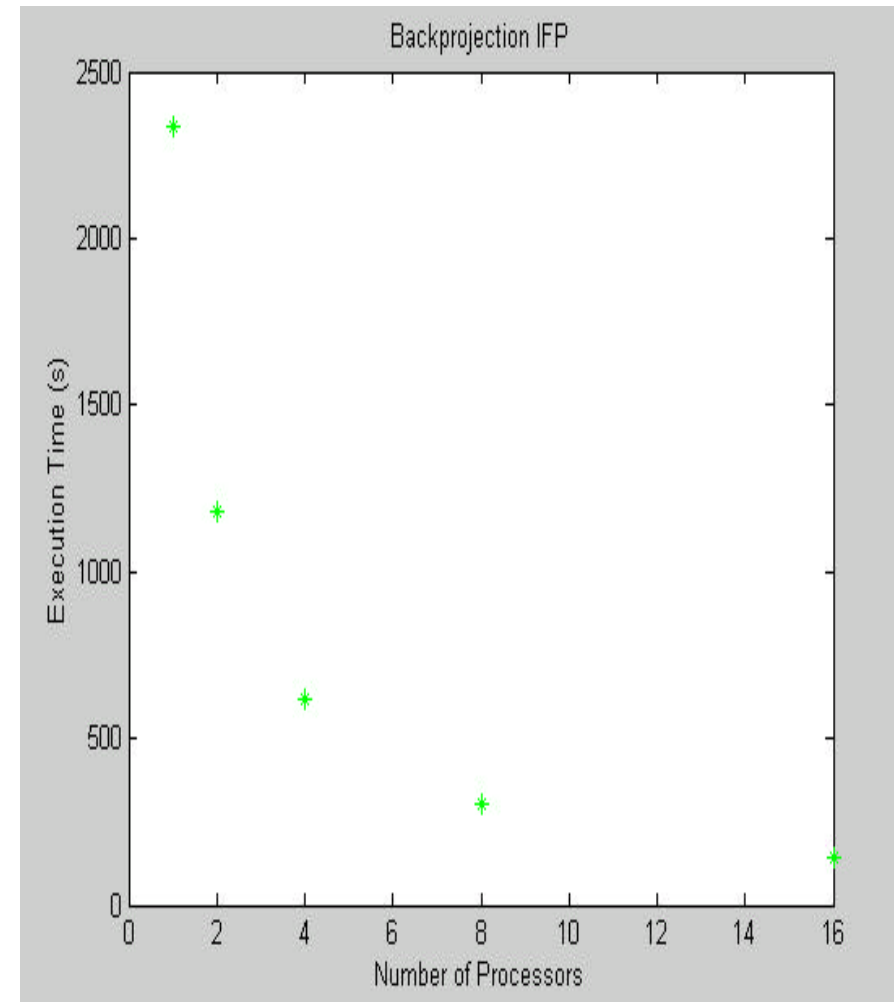
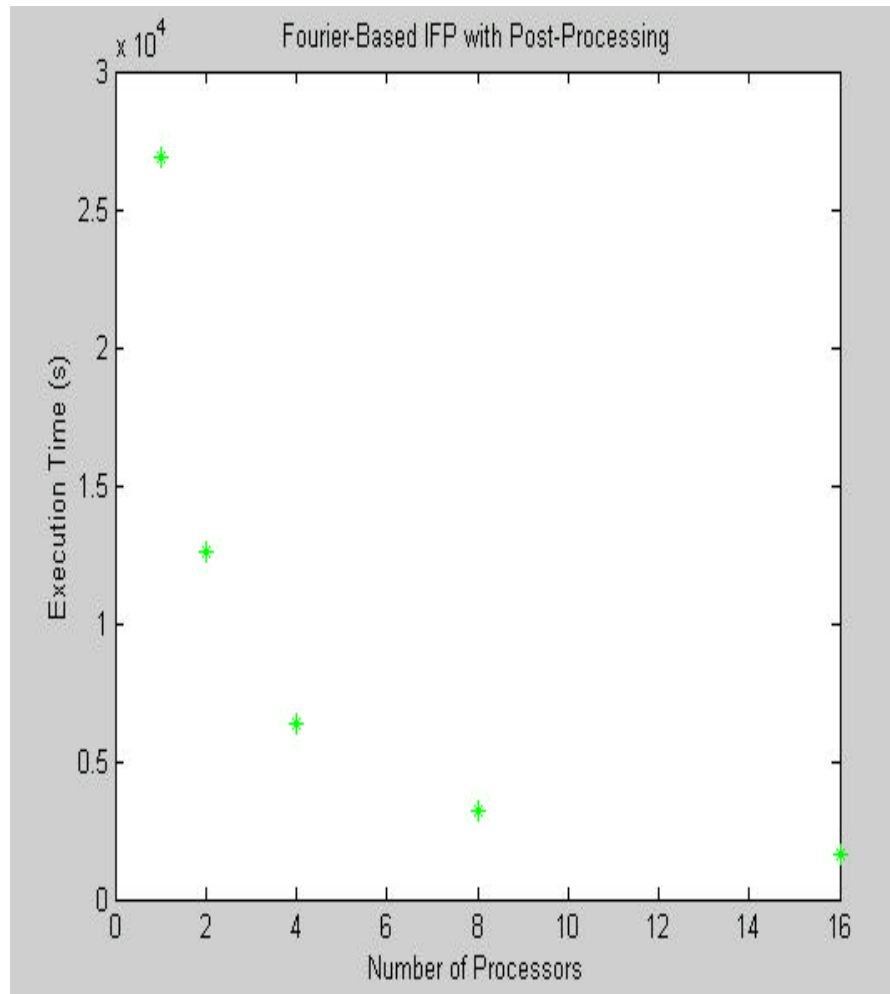
With Auto-Cal





# HPC Analysis

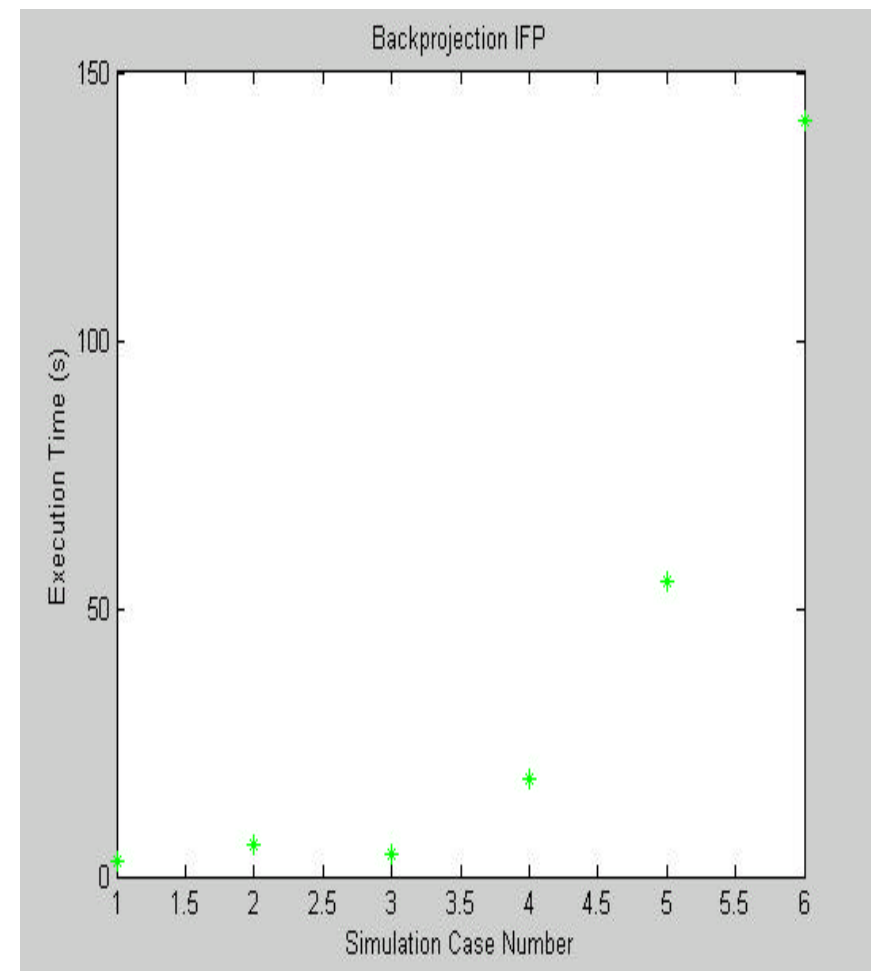
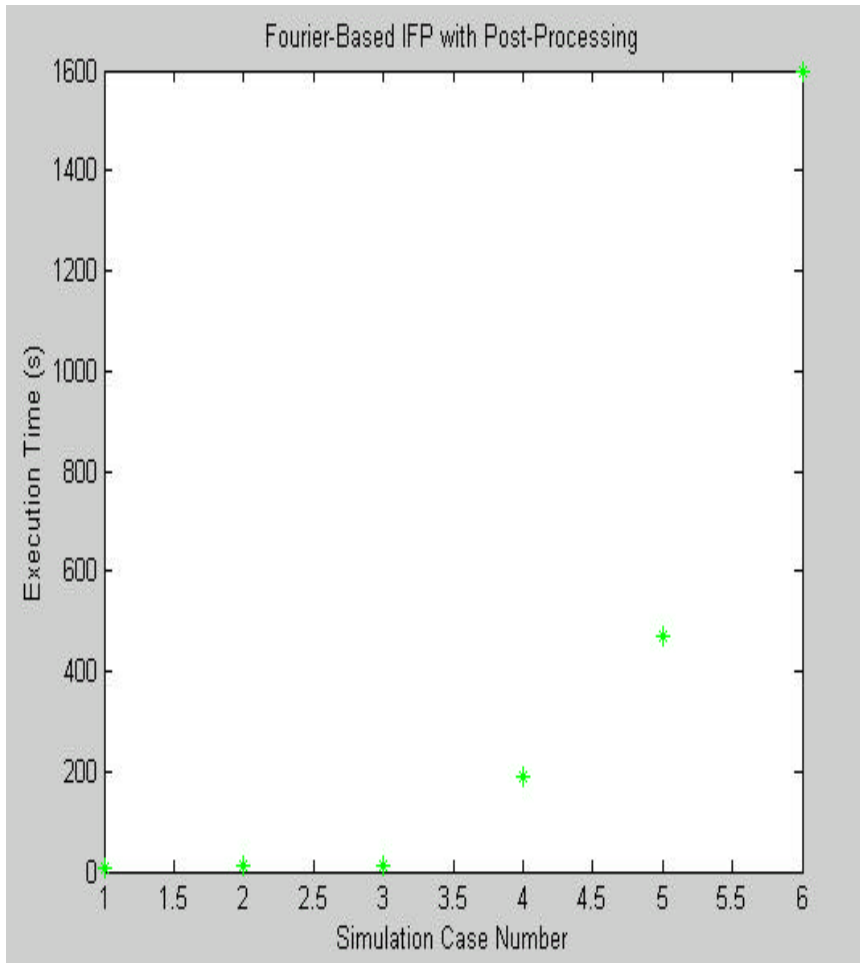
## Case 6





# HPC Analysis

## 16 Processors





# Summary

- **Parallel Implementations for Three Approaches To IFP for Real-Time UWB SAR Were Developed and Investigated**
- **Preliminary Results Indicate That Backprojection Implementation is Computationally Efficient and Generates Good Image Quality for Many Real-Time UWB SAR Applications of Interest**
- **Preliminary Results Indicate That Low-Order Interpolator for Backprojection Implementation May Generate Acceptable Image Quality for Many Real-Time UWB SAR Applications of Interest**
- **Preliminary Results Indicate That Fourier-Based IFP Processing With Intensive Auto-Cal Post-Processing Can Be Developed and Implemented To Compensate For Defocusing Errors On Systems and Scenarios That Are Associated With Significant Amounts of Residual Errors Due To Time-Dependent Sensor Fluctuations and Mo-Comp Sensor Errors**



# References

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- [1] Mehrdad Soumekh, *Synthetic Aperture Radar Signal Processing with MATLAB Algorithms*, Wiley Interscience, 1999.
- [2] W. G. Carrara, et al. *Spotlight Synthetic Aperture Radar Signal Processing Algorithms*. Artech House, 1995.
- [3] A. F. Yegulalp, "Fast Backprojection Algorithm for Synthetic Aperture Radar," Proceedings of the IEEE National Radar Conference, 1999, pp. 60 – 65.